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Foreign Transfers and Tropical Deforestation: What Terms of Conditionality?

Daan van Soest and Robert Lensink

The international community considers the possibility of using aid as an instrument to improve natural resource conservation in developing countries. By making the amount of transfers dependent on the efforts of the recipient countries to improve conservation, appropriate incentives can be given. We propose a transfer function in which developing countries are linearly rewarded for having a positive *stock* of forest, and where the amount of donations is negatively related to the *rate* of deforestation. This transfer function enables the international community to improve long-term forest conservation as well as the rate of deforestation during the adjustment period.

Key words: conditionality, deforestation, foreign transfers, land allocation model.

International concern about the global consequences of environmental degradation in developing countries has increased considerably over the last twenty years. Given the fact that the global marginal benefits of environmental protection very often exceed its domestic marginal benefits because environmental degradation has transboundary effects, a level of environmental protection develops that is suboptimally low from the point of view of the international community. This implies that, if industrialized countries indeed want improved protection of the environment in developing countries, they should be willing to compensate them financially. Therefore, the international community contemplates conditioning foreign aid donation or debt reduction on the efforts of developing countries' governments to combat environmental degradation (Jepma; Kolk 1996, 1998; Van Kooten, Sedjo, and Bulte).

One of the principal resources to which these considerations apply is tropical rainforests. Deforestation occurs mainly because forested land is converted to agricultural use. Although most rainforests can be described as open-access resources, governments of tropical forested countries affect the rate of deforestation considerably. Partly, those governments stimulate deforestation directly as they develop land use plans in which part of the forests is designated to be converted to agricultural use. They also affect deforestation indirectly by developing agricultural colonization programs in rainforests and by increasing the profitability of agriculture, through changes in the prices of natural resources and agricultural output. In this decision-making process, the flow of services provided by the rainforests (such as storage of greenhouse gases and conservation of biodiversity) that have beneficial transboundary consequences is largely ignored precisely because no compensation takes place. The existence of these externalities gives a justification for financial transfers to induce developing countries to conserve the forests.

In practice, several initiatives have been taken to improve forest conservation in developing countries. One is the debt-for-nature swap, carried out by both private organizations and governments of industrialized countries. Typically, a portion of a developing country's external debt is converted (at a discount) to domestic currency obligations, which are often placed in an environmental trust fund. These funds are used by local environmental organizations to attain their objectives, such as management of protected areas. One of the main disadvantages

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is that a developing country's government may decide to renege on actions promised in the debt-for-nature agreement, or even seize the conservation fund. Given sovereignty, it is difficult to enforce the debt-for-nature agreement as sanctions are lacking. The consequences are that projects are generally avoided that may be contrary to the government's self-interest, and that debt-for-nature swaps are implemented only in politically stable countries (Deacon and Murphy).

Given the once-and-for-all nature of debt-for-nature swaps, it may be useful to establish a more long-term relationship with local governments, where local governments are continuously rewarded for their conservation efforts. An initiative of this type is the Global Environment Facility (GEF), which was created in 1991 through a joint effort of the World Bank, the Environmental Programme of the United Nations (UNEP), and the United Nations Developmental Programme (UNDP). GEF provides concessional funding to developing countries for projects that deal with threats to biological diversity, climate change, pollution of international waters, and depletion of the ozone layer (World Bank, p. 133). Projects to counter deforestation are also eligible for funding, if they are related to one of these four main areas. This scheme is an improvement relative to debt-for-nature swaps because funds are provided periodically rather than once-and-for-all, so that lack of compliance by local governments can be discouraged by threatening to cut the aid flow.

Conditional transfers have also received a substantial amount of attention in the economic literature. Some papers focus on the effects of lump-sum donations of aid. This type of aid donation can be an effective instrument to combat deforestation, since it reduces the necessity to exploit forests in order to earn foreign exchange (Barbier and Rauscher, Pearce and Warford, p. 17). However, this is a rather passive way to use the instrument of foreign transfers. Attention is now shifting to how aid can be used more actively by making the amount of transfers conditional on the efforts of tropical forested countries to improve forest conservation (Kolk 1996, 1998). An important theoretical contribution to this literature is Stähler, who proves that long-run forest conservation can be improved unambiguously if a fixed transfer is given per unit of forest conserved. However, the impact of such a scheme on short-run conservation performance should also be analyzed. Since tropical deforestation is to a large extent irreversible, the slower deforestation takes place, the better (Dudley, Jeanrenaud, and Sullivan, p. 3, Kolk 1996).

This paper analyzes how the international community may improve both short- and long-run forest conservation by conditioning foreign aid transfers. We propose a transfer function in which developing countries are linearly rewarded for having a positive *stock* of forest, but the amount of the donation is negatively related to the *rate* of deforestation. With respect to the dependency on the rate of deforestation we propose both linear and quadratic dependency. We will show that linearly rewarding on the basis of the forest stock and linearly punishing on deforestation have similar consequences in terms of short- and long-term forest conservation. However, the financial consequences differ substantially. We will also show that by using this transfer function, the donor countries can both improve long-term forest conservation as well as the rate of deforestation during the adjustment period. In practice, most aid contracts only deal with one side of the coin: countries are rewarded for a policy that improves forest conservation, but are not "punished" for short-run deforestation. We show that, from the point of view of the donor countries, these policies are welfare improving in the long run, but suboptimal in the short run.

The main contributions of the paper are the following. First, we solve for both the long-run equilibrium and the adjustment path, whereas Stähler does not consider the adjustment path. Second, we use a fairly sophisticated land allocation model for the aid recipient. This allows us to examine in much greater detail the channels by which the aid conditionality affects long- and short-run forest conservation. Third, we explicitly solve for optimal values in the aid allocation function by assuming different weights in the utility function of the donor community.

We start by formulating the objectives of the donor community and by identifying the constraints it faces. Next the actions of the aid recipient are considered. We show the consequences of the proposed compensation function in terms of both short- and long-run forest conservation. Then we numerically derive the values of the parameters in the aid donation function that maximizes the donor community's utility. Finally, conclusions are drawn and the policy implications of our theoretical analysis are derived.

The Model for the Donor Community's Optimization Problem

The aim of the paper is to derive an aid donation function that best serves the donor community's interest in terms of rainforest conservation. The problem is solved recursively in the sense that first the recipient country's optimal response to a specification of the aid donation function is derived, after which the donor community sets the donation function's parameters at their optimal level. The donor community offers an aid contract in which the terms of conditionality are spelled out. The recipient chooses the rate of deforestation to maximize its own utility, given the terms of the contract. We assume that there is complete information and that the donor costlessly monitors the actions of the recipient. Therefore, the donor community knows the optimal level of action of the aid recipient for each possible contract. Hence the donor is able to devise the contract in such a way that the action of the aid recipient is optimal for the donor. However, since the aid recipient can refuse the contract, the donor community should take a participation constraint into account in devising the optimal contract. This implies that the developing country's welfare when it accepts the contract is at least equal to its welfare if the contract is not accepted.

The maximization problem of the donor community is as follows:

$$(1) \quad V = \max \int_0^\infty e^{-rt} U(F(t), S(t))\, dt$$

$$(2) \quad \text{s.t.} \qquad S(t) = S(F(t), D(t))$$

$$(3) \quad \dot{F}(t) = -D(t)$$

$$(4) \quad W_S \geq W_{NS}.$$

The donor community maximizes the discounted value of its instantaneous utility U, which depends positively on the size of the forest stock (F, measured in units of land) and negatively on the foreign aid transfer (S). Equation (2) describes the aid contract of the donor community. In Stähler's model, the compensation function depends only on the forest stock in each period. We include the possibility of punishment based on deforestation (D, also measured in units of land) since, as will be shown in the next section, this will give the donor community a better opportunity to improve both short- and long-run forest conservation. Equation (3) states that the change in forest size ($\dot{F}$) equals the rate of deforestation. Finally, equation (4) is the participation constraint. This equation guarantees that the discounted value of the *net* revenues for the aid recipient if it participates (W_S) is at least as high as the discounted value of the revenues when it rejects the aid contract (W_{NS}).[1]

The next section describes the decision-making process of the recipient country that maximizes its own welfare by choosing an optimal rate of deforestation in each period (given the specification of the aid contract).

The Model for the Aid Recipient

A study of using foreign aid to improve forest conservation requires a model that allows for a realistic explanation of how deforestation takes place. This implies that the model should compare the revenues that can be obtained from forest conservation, or selective logging, with the revenues from deforestation. With regard to the revenues from deforestation, the income obtained from selling timber is obvious. However, it is extremely important that the revenues from alternative land use are also considered (see Chomitz and Kumari). It is well known that one of the main *direct* causes of deforestation in rainforest areas is conversion to agricultural land.[2] With respect to the financial revenues from forest conservation, an important issue is the positive effect of the proximity of forests on agricultural productivity. Furthermore, there are market forces, such as changes in prices of timber, which may lead to an automatic stop to deforestation overtime (Hyde, Amacher,

[1] In the remainder of the text, subscript S denotes the value of the variable when the aid donation function is in place while subscript NS denotes its value in the absence of an aid contract.

[2] Although agricultural activities are not necessarily incompatible with forest conservation, in practice incentive structures (e.g., arising from government policy or inadequate tenure systems) are such that agricultural conversion results in actual deforestation (Repetto and Gillis). Forestry activities can also inflict substantial damage upon the forests, but they rarely result in actual deforestation (Cannon, Peart, and Leighton). The forestry technique most often applied is selective logging, in which only a few trees of high commercial value are logged and extracted.

and Margrath, Vincent and Gillis). Hence, especially when both the adjustment path of deforestation and the long-run equilibrium are study objects, as is the case in this paper, it is important that the model allows for relative price changes.

Probably the best model available that deals with the above mentioned issues is the one by Ehui, Hertel, and Preckel. With a few minor adaptations, this model is able to capture the full consequences of the impact of conditional aid donation on the allocation of land to forestry and agriculture. It allows for an analysis of not only the long-run equilibrium but also of the depletion path toward it. In the model the government of a country endowed with rainforests aims to maximize the net present value of forest exploitation, choosing the optimal rate of deforestation in each period. We have modified their model by simplifying it somewhat, by taking into account that conversion timber can be sold, by specifying all equations explicitly, and by adding a conditional transfer function.[3] Our model is as follows:

$$W = \max_D \int_0^\infty R(t)e^{-rt}\,dt \tag{5}$$

$$\text{s.t.} \qquad \dot{F}(t) = -D(t) \tag{6}$$

$$R(t) = P(t)q(t) + P_A(t)Z(t) \times [F_0 - F(t)] + S(t) \tag{7}$$

$$q(t) = nD(t) + \gamma n(F(t) - D(t)) \tag{8}$$

$$P(t) = \bar{P} - \theta q(t) \tag{9}$$

$$Z(t) = \bar{Z} + \alpha D(t) - \beta[F_0 - F(t)] \tag{10}$$

$$S(t) = S(F(t), D(t)). \tag{11}$$

In this model, the net present value of instantaneous net revenues[4] ($R(t)$, discounted at rate r) is maximized by choosing the optimal rate of deforestation (D) in each period (equation (5)). Depletion of the forest stock is represented by the equation of motion (equation (6)). The size of the forest stock (F) falls over time at the rate of deforestation.

Equation (7) shows that revenues are derived from forestry activities, agricultural production, and foreign transfers. Forestry revenues in each period are equal to the quantity of timber supplied (q) in that period multiplied by the prevailing price (P) in that period. The quantity produced q is presented in equation (8). Suppose that there are n commercially valuable stems per unit of land. Timber is produced using either clearfelling or selective logging. Clearfelling takes place on land that is to be converted to agricultural land. Under clearfelling all commercially valuable timber is removed; the quantity of timber produced through clearfelling thus equals n times D. Timber is also produced using selective logging techniques (which do inflict some damage upon the forests but do not cause a permanent reduction in biomass). Under selective logging, only a fraction of the timber is extracted, which is reflected by parameter γ, with $\gamma < 1$. The amount of timber produced through selective logging thus equals the amount of commercially valuable timber extracted per unit of land (γ times n) multiplied with the area that is *not* converted to agricultural use ($F - D$).[5] For convenience, we set n equal to one, so that the timber price P reflects the value of all commercially valuable timber present per unit of land. For mathematical simplicity, the timber demand function is assumed to be linear (see equation (9)).[6]

The second term in equation (7) represents agricultural revenues. These equal the monetary yield per unit of land times the amount of land under cultivation ($F_0 - F(t)$, where F_0 is the initial size of the rainforest area). All deforested land is converted to agricultural land, which is assumed to become productive instantaneously. The monetary yield consists of the price of agricultural products (P_A, which is assumed to be fixed at $\bar{P}_A$),[7]

[3] The reader will note that the Ehui, Hertel, and Preckel (EHP) model is already quite complicated. Simpler models are available such as Stähler, which uses a concave utility function with deforestation as the only argument. However, the EHP model provides a much richer explanation of how deforestation takes place over time. This is important when one wants to examine how aid should be conditioned in order to improve both long- and short-run forest conservation.

[4] We assume all production to be costless: including costs would only complicate the mathematics without changing the results. Hence, the terms revenues and net revenues can be used interchangeably.

[5] Alternatively, equation (8) can be rewritten as $q = \gamma nF + (1 - \gamma)nD$. The entire forest area is logged selectively (yielding an amount of timber equal to γnF). In the area to be converted, clearfelling implies that the remaining fraction of timber ($(1 - \gamma)n$) is also harvested, yielding an amount of timber equal to $(1 - \gamma)nD$.

[6] The use of a downward-sloping timber demand function is based on a survey of the literature presented by Barbier et al. (p. 43). They show that indeed the tropical timber demand function is downward sloping at a country level. It can easily be shown that our main results are not affected by this assumption.

[7] The assumption of a fixed price for agricultural produce facilitates the mathematics without changing the results.

multiplied by the average per-unit land productivity Z. As is reflected in equation (10), land productivity is not fixed. On the one hand, current deforestation (D) contributes to average soil productivity. Burning of the forest cover increases average soil productivity because of the release of nutrients (Hecht). A newly deforested area is very fertile in the short run, but it can be cultivated for only a limited period of time. Soil productivity falls quickly during cultivation because of nutrient depletion (López and Niklitschek, OTA). Therefore, only *current* deforestation contributes to average soil productivity. On the other hand, the proximity of forest cover increases average soil productivity because it prevents erosion and accelerates soil formation by shedding organic material onto the fallow land (Ehui, Hertel, and Preckel). Hence, *cumulative* deforestation ($F_0 - F$) has a negative effect on average soil productivity.[8]

The third source of revenue is a foreign transfer (equation (11)). The general form of this equation has already been described in the previous section (see equation (2)).

The solution of this model yields a net present value which is denoted W_S. If no aid is given, equation (11) can be ignored, S equals zero in equation (7), and the resulting net present value is denoted as W_{NS}.

The equilibrium size of the forest area is found by solving the current value Hamiltonian of the model:

$$(12)\qquad H(D, F, \lambda) = [Pq + \bar{P}_A Z[F_0 - F] + S(D, F)] - \lambda D.$$

Applying Pontryagin's maximum principle and assuming an interior solution results in the following first-order conditions:

$$(13)\qquad \lambda(t) = (1-\gamma)P(t) + \alpha\bar{P}_A[F_0 - F(t)] - \theta(1-\gamma)q(t) + S_D$$

$$(14)\qquad \dot{\lambda}(t) = r\lambda(t) - \gamma P(t) - \beta\bar{P}_A[F_0 - F(t)] - S_F + \bar{P}_A Z(t) + \gamma\theta q(t).$$

The interpretation of equation (13) is that in each period the costs of deforesting an extra unit of forested land now rather than in the future (i.e., the current-value shadow price λ) are equal to the (net) benefits of currently deforesting that extra unit. These benefits consist of four parts. The first term on the right-hand side (RHS) reflects the direct revenues of deforestation resulting from the extra timber sold. The second term represents the increased agricultural revenues arising from the positive effect of current deforestation on agricultural productivity. The third term is the effect of a fall in the price at which the entire timber supply is sold as a result of the extra timber extracted from the deforested unit of land. The last term on the RHS is the loss in revenue caused by the conditionality of transfers on the rate of deforestation ($S_D < 0$).

Equation (14) is a straightforward extension of the Hotelling rule (Hotelling). It is an intertemporal nonarbitrage condition, which dictates that for an optimal solution no gain in profits can be achieved by reallocating deforestation from one period to another. This implies that the current-value shadow price of the forest stock should increase at rate r, reduced with the net benefits of keeping an additional unit of land forested. These net benefits are equal to the marginal return on forest conservation minus the opportunity costs of holding on to the marginal unit of forested land. The marginal return on forest conservation equals the sum of the revenue that can be earned by logging this unit of forest land selectively (γP), the value of the contribution of forest conservation to soil productivity ($\beta\bar{P}_A(F_0 - F)$), and the return in the form of transfers resulting from conditionality on changes in forest size (S_F). The opportunity costs of conserving an additional unit of forest land are the revenues earned by having an extra unit of land under cultivation ($\bar{P}_A Z$) and the timber price increase ($\gamma\theta q$) that would result from deforestation because of reduced (future) supply.

The Derivation of the Long-Run Size of the Forests and the Depletion Path

If the tropical forested country decides to participate in the contract, the equilibrium size of the rainforest area can be found by setting the time derivatives ($\dot{F}$ and $\dot{\lambda}$ in equations (6) and (14)) equal to zero.

[8] Of course, it is a crude simplification to use *average* agricultural productivity, especially when *marginal* deforestation decisions will subsequently be analyzed. However, this approach is mathematically simple and the final conclusions will not be altered qualitatively if soil productivity is modelled in a more sophisticated way.

The resulting equilibrium forest size (F^*) is[9]

$$(15)\quad F^* = F_0 - [(\bar{P}_A\bar{Z} - [\gamma - r(1-\gamma)] \times [P(F_0) - \theta\gamma F_0] + rS_D - S_F) / (P_A[2\beta - r\alpha] + 2\gamma\theta[\gamma - r(1-\gamma)])].$$

Although this equation is complex, the interpretation is straightforward. The numerator of the second term on the RHS reflects the net present value of converting the *first* unit of forest land. The present value of the economic benefits of deforesting the first unit of land is weighed against the present value of the economic benefits of selective logging. The numerator can either be postive or negative, as can be seen below:

$$(16)\quad (1-\gamma)[P(0) - \theta\gamma F_0] + \frac{\bar{P}_A\bar{Z}}{r} \overset{?}{\geq} \frac{\gamma}{r}[P(0) - \theta\gamma F_0] - S_D + \frac{S_F}{r}.$$

The LHS of (16) is the present value of the marginal revenues of deforestation, which consists of the one-shot revenues of excessive logging (taking into account the effect on the price due to the downward-sloping demand function) and the present value of the future revenues arising from the conversion into agricultural land. The RHS is the present value of the marginal costs of deforestation. The first term reflects the benefits of selective logging that would be lost (consisting of the sales price and the effect of *not* deforesting a unit of land on the sales price). The second and third terms occur because the donation function is assumed to be conditional. If the scheme depends on *current* deforestation only, there are one-shot losses in terms of the reduction in foreign transfers. If the scheme depends on *cumulative* deforestation, deforesting a unit of land has financial consequences not only now but also in the future. If the present value of the marginal revenue stream of deforestation (LHS) exceeds the present value of marginal revenues generated by forest conservation (RHS), at least some deforestation is desirable.

The denominator in equation (15) acts as a multiplier, which has to be positive in order to ensure the existence of an optimum. This means that if the increase in agricultural yield from *current* deforestation (α) is very large compared to the present value of the contribution of the forest stock to agricultural yield (β) given the discount rate (r), the model collapses. In their empirical application of this model, Ehui and Hertel find that in the case of Ivory Coast the denominator is positive. In our model used in this section, the fact that the demand function for timber is downward sloping (θ is positive) implies that it is even more likely that the denominator is positive.[10]

In order to derive the depletion path, the transfer function needs to be explicitly specified. The results of Stähler imply that linear dependency on the size of the forest stock (F) is expected to improve forest conservation. With respect to dependency on the rate of deforestation (D), it may prove to be useful to assume both linear and quadratic dependency. Therefore, we construct the following specification:

$$(17)\quad S(t) = aF(t) - cD(t) - \frac{d}{2}(D(t))^2.$$

Since the rate of deforestation equals zero in long-run equilibrium, this specification implies that S_F equals a and S_D equals $-c$ in equation (15). The depletion path toward the long-run equilibrium can be calculated by taking the time derivative of the costate variable λ in (13), inserting the result together with the equation of motion (6) and the specified transfer function (17) into equation (14), and solving the resulting second-order differential equation (Apostol, pp. 322–28):

$$(18)\quad F(t) = (F_0 - F^*) \cdot \mathrm{EXP}\left\{ -[(\tfrac{1}{4}r^2 + [\bar{P}_A(2\beta - r\alpha) + 2\gamma\theta(\gamma - r(1-\gamma))] \cdot [d + 2\theta(1-\gamma)^2]^{-1})^{1/2} - \tfrac{1}{2}r]t \right\} + F^*.$$

It is noteworthy that, unlike d, the parameters a and c do not enter the exponent of

[9] The steady state solution of this model satisfies the transversality condition that either the forest stock or its present-value shadow price should go to zero as time goes to infinity.

[10] The assumption that initially the entire forest area is logged selectively rather than by clearfelling implies that the discounted profits of selective logging ($\gamma P(0)/r$) exceed the one-shot profits of clearing the residual stand ($(1-\gamma)P(0)$). Consequently, the term ($\gamma - r(1-\gamma)$) is positive.

equation (18). Parameters a and c only indirectly affect $F(t)$ by increasing the equilibrium forest size F^*. In the next sub-section the implications of this for effects of changes in the parameters of the compensation function on both the long-run equilibrium forest size as well as on the forest size during the adjustment period are considered.

The Environmental Consequences of the Choice of the Compensation Function

We start the analysis by considering the effects of conditioning transfers on the remaining stock of the forest area. In general, rewarding forest conservation gives an incentive to achieve a higher size of the forest area in the long run and in the short run, as can be seen by calculating the first derivatives of F^* and $F(t)$ with respect to a:

$$\text{(19)} \quad \frac{\partial F^*}{\partial a} = \frac{1}{(2\beta - r\alpha)\bar{P}_A + 2\theta\gamma(\gamma - r(1-\gamma))} > 0$$

$$\text{(20)} \quad \frac{\partial F(t)}{\partial a} = \left\{1 - \mathrm{EXP}\left\{-\left[\left(\tfrac{1}{4}r^2 + [\bar{P}_A(2\beta - r\alpha) + 2\gamma\theta(\gamma - r(1-\gamma))] \cdot [d + 2\theta(1-\gamma)^2]^{-1}\right)^{1/2} - \tfrac{1}{2}r\right]t\right\}\right\} \times \frac{\partial F^*}{\partial a} > 0.$$

Equation (19) shows that, if a tropical forested country receives a certain amount of money for each unit of forest land left, forest conservation is improved in the long run; i.e., the equilibrium forest size is increased. The donation of a fixed amount of money per unit of forest land also affects the instantaneous *rate* of deforestation. Equation (20) shows that increasing a results in an increase in forest cover in each period. Hence, if the compensation function is linear in F (i.e., $S = aF$), per-unit compensation is fixed and forest conservation is improved both in the long and in the short run. The short-run effect arises exclusively from the fact that increasing a decreases the optimal amount of cumulative deforestation $(F_0 - F^*)$, which implies that the area deforested in each period should also be lower.

When the *rate* of deforestation is included in the compensation function, the comparative static results are as follows:

$$\text{(21)} \quad \frac{\partial F^*}{\partial c} = r\frac{\partial F^*}{\partial a}$$

$$\text{(22)} \quad \frac{\partial F(t)}{\partial c} = r\frac{\partial F(t)}{\partial a} > 0.$$

Hence, increasing c also improves the long-run equilibrium size. However, as is clear from (21), rewarding forest conservation will have a larger positive impact on the long-run equilibrium forest size than conditioning on the *rate* of deforestation: increasing parameter c by one unit results in an increase in long-run forest size that is only a fraction r of the improvement achieved by increasing parameter a by one unit. The reason is that deforesting a unit at a certain moment only has a one-period impact in case of conditioning on the flow indicator whereas the negative effect lasts forever if conditioning is based on the stock variable. Equation (22) shows that increasing c also reduces the short-run rates of deforestation. However, again this exclusively results from a reduction in total cumulative deforestation.

The comparative statics results with respect to parameter d are as follows:

$$\text{(23)} \quad \frac{\partial F^*}{\partial d} = 0$$

$$\text{(24)} \quad \frac{\partial F(t)}{\partial d} = \frac{1}{2}t(F(t) - F^*) \cdot \left\{\tfrac{1}{4}r^2 + [\bar{P}_A(2\beta - r\alpha) + 2\gamma\theta(\gamma - r(1-\gamma))] \cdot [d + 2\theta(1-\gamma)^2]^{-1}\right\}^{1/2} \times \frac{\bar{P}_A(2\beta - r\alpha) + 2\theta(\gamma - r(1-\gamma))}{[d + 2\theta(1-\gamma)]^2} > 0.$$

From equation (23) it is clear that d does not affect F^*: letting transfers depend negatively on the rate of deforestation in a nonlinear way does not have an effect on long-run forest conservation. The reason is that by definition deforestation is zero in the steady state. However, “punishing” quadratically on current deforestation does affect the path directly by changing the value of the exponential term in (18). This occurs because (24) implies that the forest size is increased in every period as d is increased. The marginal reduction of transfers increases with the rate of deforestation so that the recipient country has an incentive to flatten the depletion path over time.

On the basis of the comparative statics analysis, two main conclusions can be drawn. First, long-run forest conservation can be improved by linearly punishing on deforestation or by rewarding forest conservation using a fixed per-unit compensation price. Second, in order to improve short-run forest conservation in a direct way, the donor community should punish deforestation at an increasing rate. Thus, the policy of rewarding on the basis of the forest stock and linearly punishing on deforestation are effective in improving long-run forest conservation, whereas a policy of "punishing" quadratically on the rate of deforestation has a strong beneficial impact on forest conservation during the adjustment period.

The Welfare Consequences of the Choice of the Compensation Function

In the previous section we have shown that the *environmental* impact of a change in a is directly proportional to the impact of a change in c while the impact of parameter d on the depletion path and long-run forest stock is radically different. However, the *financial consequences* of a and c differ substantially, thus affecting the donor community's utility and the recipient countries' welfare. Up until know, the analysis has ignored the welfare impact of the specification of the aid contract. The impact on the recipient countries' welfare is especially important. The donor community's choice of a, c, and d is constrained by the fact that the contract should be such that participation is not detrimental to tropical forested countries.

Therefore, the final step in the analysis is the determination of a combination of the parameters a, c, and d that maximizes the present value of the donor's utility, given the actions of the recipients, as well as the participation constraint. Assume, for reasons of convenience, a linear specification for the donor's utility function (1):

$$(25)\quad V = \max_{a,c,d} \int_0^{\infty} [\nu F(t) - wS(t)]e^{-rt}\,dt$$

where ν and w are the weights of forest conservation and expenditures on aid, respectively. The model is solved as follows. The tropical forest country's optimal depletion path is calculated first, taking parameters a, c, and d as given. Then we insert the resulting paths of F and D in the donor community's decision problem, and maximize the discounted value of its utility flow with respect to parameters a, c, and d for rather arbitrary values of ν and w.[11] For reasons of space, we do not present the detailed derivations here.

Given the complexity of the model, analytical solutions cannot be derived. However, presenting some of the numerical solutions provides insight into the underlying mechanisms of the model. Table 1 presents results for three combinations of ν and w.

Given that the size of the equilibrium rainforest area in the case where the aid recipient does not participate in the aid contract (F^*_{NS}) is 1,294, the table shows that the donor community is indeed able to improve long-run forest conservation. For all contracts applied in this table the long-run equilibrium size of the rainforest area is above the equilibrium size of the rainforest area when the recipient does not participate. Therefore, the donor community is able to devise an aid contract that satisfies the participation constraint and at the same time reduces the depletion of the rainforest area. The donor community is also better off under an aid scheme: the discounted value of the donor community's utility under an aid scheme (V_S) always exceeds the value in the absence of such a scheme (V_{NS}).

The table also shows, as expected, that transfers increase when donors care more about preserving the rainforest area (compare the first and second scenario in table 1). Furthermore, if the disutility of provided funds falls (compare the first and third scenario in table 1), both the long-run equilibrium rainforest area (F^*_S) and the amount of funds provided (S^*) increase. The changes in the values of the control variables are as follows. An increase in the marginal utility of forest conservation (ν) or a decrease in the marginal disutility of spending money (w) results unambiguously in a higher compensation per unit of forest conserved (a). For the other two control variables, no straightforward conclusions can be drawn. In general there is a trade-off between the two: an

[11] The derivation comes down to solving the integral (equation (25)), setting up a Lagrangian by taking into account the participation constraint, and finally taking the first derivatives with respect to a, c, d, and the Lagrangian multiplier. The derivations can be obtained from the authors on request.

Table 1. The Optimal Values of *a*, *c*, and *d* for Different Values of *v* and *w*, and the Resulting Long-Run Forest Size (F_s^*), Discounted Value of Aid Donated (S^*), and Net Improvement in the Discounted Value of the Donor Community's Utility ($V_S - V_{NS}$)

(v, w)	(1, 0.0001)	(5, 0.0001)	(1, 0.00001)
a	874.57	982.53	935.42
c	2,519.29	8,704.23	2,472.99
d	61.90	31.44	70.40
F_S^*	1,352.57	1,390.04	1,355.48
S^*	3,907,027	5,068,652	4,508,311
$V_S - V_{NS}$	1,034.48	6,546.37	1,493.77

Parameter values: $\bar{P}=40{,}000$, $\theta=20$, $\bar{P}_A=100$, $\gamma=0.15$, $r=0.1$, $\bar{Z}=250$, $\alpha=0.1$, $\beta=0.1$, $F_0=2{,}500$.

increase in either c or d implies that the other control variable should be decreased in order to satisfy the participation constraint. For the parameter values chosen, an increase in v results in an increase in c and a decrease in d. Apparently, a strong increase in the long-run equilibrium size of the forest (with subsequent positive effect on the depletion path, albeit limited) is preferred to a substantial improvement in short-run forest conservation. A decrease in w has the opposite effect: c is lowered and d is increased.

It must be remarked that the results are fairly sensitive to the relative size of the parameters v and w. The reason for this is the specification of the donor community's utility function: given the difference in magnitude of the two arguments, the values of the respective parameters have to be adjusted accordingly.

The impact of designing a compensation scheme using optimal values for a, c, and d can also be shown graphically. Figure 1 presents two cases for different preferences of the donor community and the path that results when no aid is provided. The line resulting in the largest long-run forest size represents the depletion path in the case where $v=5$ and $w=0.0001$. The line resulting in a somewhat lower long-run forest size corresponds to the case where $v=1$ and $w=0.00001$. The lowest line represents the depletion of the rainforest area when no aid is provided (non-participation). The graph clearly shows that aid contracts not only increase the equilibrium forest area but also lengthen the path to the equilibrium. Hence, rainforest conservation is improved in both the short and long run.

Conclusions and Policy Implications

This paper presents an analysis of the consequences of making aid dependent on forest conservation in order to reduce the attractiveness of deforestation from the point of view of tropical forested countries. It is shown that rewarding forest conservation by paying a fixed amount of money per unit of forest conserved increases forest conservation unambiguously in the long run. Improving the long-run size implies that cumulative deforestation falls, and hence that the area deforested will be smaller in each period. This means that this instrument is fairly effective in improving long-run forest conservation, but only slightly so in improving short-run conservation.

A more active short-run policy may be envisaged where transfers also depend negatively on current deforestation. We show that *linear* dependency has similar consequences in terms of short- and long-run forest conservation than has rewarding forest conservation using a fixed per-unit compensation price. However, we also show that the donor community's utility and the recipient countries' welfare are affected differently due to different financial effects. Moreover, we show that short-run forest conservation is best achieved when the donor community decides to decrease aid donations at an increasing rate when the rate of deforestation rises.

Conditioning financial aid on the developing countries' efforts to protect the environment has been implemented for more than a decade, under programs such as the debt-for-nature swaps and GEF. However, both these initiatives suffer from the same drawback: positive policies are rewarded, but negative policies are not punished. We propose to make the forest conservation plan part of an overall World Bank or IMF funded

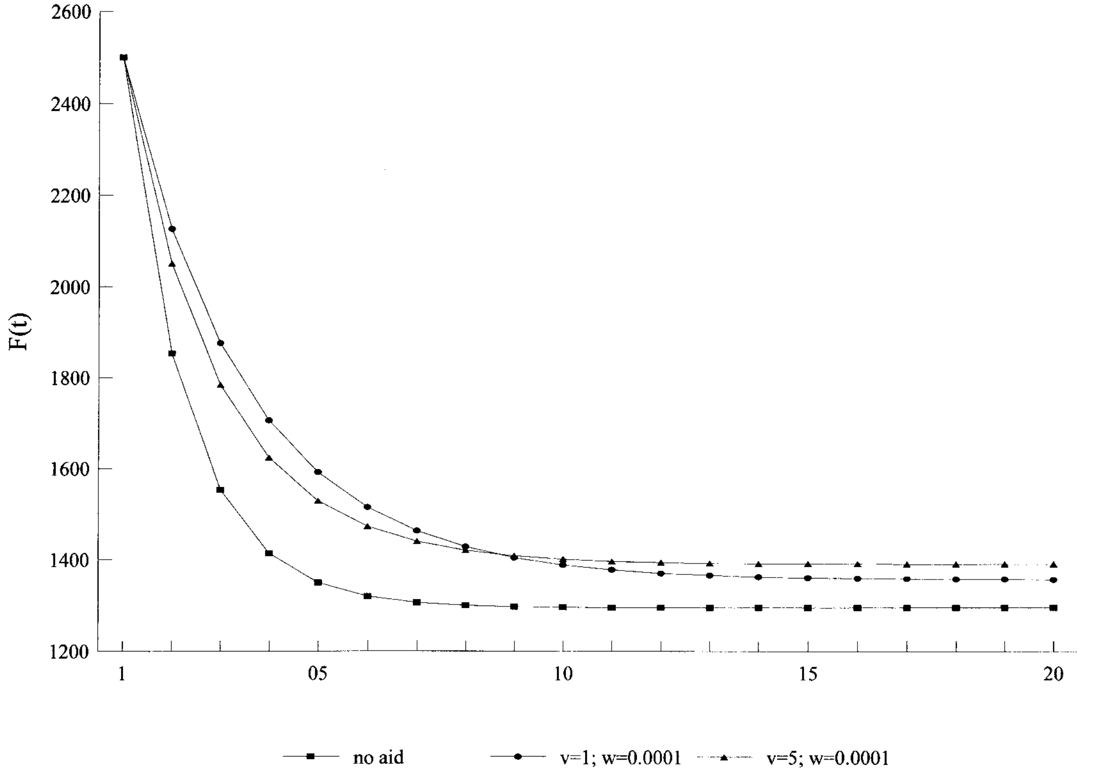

Figure 1. The depletion path resulting from the donor community's optimal combination of reward and punishment for (v, w) is (1, 0.00001) and (5, 0001), compared with the path in the absence of an aid scheme

structural adjustment program, where the aid contract is made dependent on both the forest stock and the rate of deforestation.

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